CHAPTER 2 Design Properties of Materials

ONLY THOSE PROBLEMS REQUIRING NUMERICAL DATA ARE SHOWN.

2-14 S_u = 90ksi (621 MPa); S_y = 60 ksi (414 MPa); 25% ELONG.
BECAUSE % ELONGATION >5%, IT IS DUCTILE. (APP. A-14)

2-15 1020 HR: 36 % ELONGATION – GREATER DUCTILITY
1040 HR: 25 % ELONGATION (APP. A-14)

2-16 AISI 1141 OQT 700: HIGH SULFUR ALLOY STEEL WITH 0.41% CARBON, QUENCHED IN OIL, TEMPERED AT 700°F. (APP. A-14)

2-17 YES. S_y = 172 ksi @ OQT 700, S_y = 129 ksi @ OQT 900
BY INTERPOLATION $S_y \approx 150$ ksi @ OQT 800. (APP. A-14)

2-18 E = 30×10⁶ psi (207 GPa) FOR ALL CARBON AND ALLOY STEELS. (APP. A-14)

2-19 WT = DENSITY × VOLUME = $(0.283\ \text{LB/in}^3)(1.0)(4.0)(14.5)\ \text{in}^3 = \underline{16.4\ \text{LB}}$
(APP. A-14) VALUE OF LB_m = VALUE OF LB FORCE (WT.)

2-20 VOLUME = AREA × LENGTH = $\frac{\pi}{4}(50)^2 \times 250 = 4.909\times10^5\ \text{mm}^3$
STEEL BAR

$$\text{MASS} = \frac{7680\ \text{kg}}{\text{m}^3} \times \frac{4.909\times10^5\ \text{mm}^3}{1} \times \frac{1\ \text{m}^3}{(10^3\ \text{mm})^3} = 3.77\ \text{kg}$$

(APP. A-14)

$$\text{WT} = m\cdot g = 3.77\ \text{kg} \cdot 9.81\ \text{m/s}^2 = 36.98\ \text{kg}\cdot\text{m/s}^2 = \underline{36.98\ \text{N}}$$

2-21 MAGNESIUM WOULD BECAUSE IT HAS A LOWER E.
E_{MAG} = 45 GPa; E_{Ti} = 114 GPa; Ti IS STIFFER. (APP. A-15)

2-23 ALLOY OF ALUMINUM WITH SILICON AND MAGNESIUM.
HEAT TREATED TO T6 TEMPER.

2-28 (APP. A-18)

	S_u	S_y	E	DENSITY
6061-O	18 ksi	8 ksi	10×10⁶ psi	0.10 LB/in³
6061-T4	35 ksi	21 ksi	"	"
6061-T6	45 ksi	40 ksi	"	"

2-29 S_{ut} = 40 ksi; S_{uc} = 140 ksi (APP. A-17)

2-31 BENDING σ_d = 1450 psi; TENSION σ_d = 850 psi; COMP. 1000 psi PARALLEL TO GRAIN, 385 psi PERPENDICULAR TO GRAIN; SHEAR τ_d = 95 psi (APP. A-19)

2-32 2000 TO 7000 psi (SECTION 2-10)

2-44 Graphite fibers.

2-45 S-glass, quartz fibers, tungsten fibers coated with silicon carbide.

2-51

Material	*Specific strength (in)*	*Ratio to AISI 1020*
Graphite/Epoxy (High Strength)	4.86×10^6	25.0
Aramid/Epoxy Composite	4.00×10^6	20.6
Boron/Epoxy Composite	3.60×10^6	18.5
Graphite/Epoxy (Ultra-hi mod)	2.76×10^6	14.2
Glass/Epoxy Composite	1.87×10^6	9.63
Titanium Ti-6Al-4V	1.00×10^6	5.15
AISI 5160 OQT 700 Steel	0.929×10^6	4.78
Aluminum 7075-T6	0.822×10^6	4.23
Aluminum 6061-T6	0.459×10^6	2.36
AISI 1020 HR Steel	0.194×10^6	1.00

2-52

Material	*Specific modulus (in)*	*Ratio to AISI 1020*
Graphite/Epoxy (Ultra-hi mod)	8.28×10^8	7.81
Boron/Epoxy Composite	4.00×10^8	3.77
Graphite/Epoxy (High Strength)	3.45×10^8	3.25
Aramid/Epoxy Composite	2.20×10^8	2.07
AISI 1020 HR Steel	1.06×10^8	1.00
AISI 5160 OQT 700 Steel	1.06×10^8	1.00
Titanium Ti-6Al-4V	1.03×10^8	0.97
Aluminum 6061-T6	1.02×10^8	0.96
Aluminum 7075-T6	0.99×10^8	0.93
Glass/Epoxy Composite	0.66×10^8	0.62

2-60 $V_m = 1 - V_f = 1.0 - 0.60 = 0.40$

2-61 See Equation (2-10).

2-62 See Equations (2-11), (2-12), (2-13), (2-14).

2-63 Given: $V_f = 0.50$; Fibers are high strength carbon-PAN; Matrix is Epoxy

See Table 2-15 for data. $V_m = 1 - V_f = 1.0 - 0.50 = 0.50$

Use Equation (2-10): $s_{uc} = s_{uf}\, V_f + \sigma_m'\, V_m$

Strain at which fibers would fail: $\varepsilon_f = s_{uf} / E_f = (820\text{x}\ 10^3 \text{ psi})/(40\text{x}10^6 \text{ psi})$

$\varepsilon_f = 0.0205$

Stress in matrix at this strain: $\sigma_m' = E_m\, \varepsilon = (0.56\text{x}10^6 \text{ psi})(0.0205) = 11\ 480 \text{ psi}$

Then: $s_{uc} = (820\text{x}\ 10^3 \text{ psi})(0.50) + (11\ 480 \text{ psi})(0.50) = \underline{415\text{x}10^3 \text{ psi}}$

Modulus of elasticity: $E_c = E_f\, V_f + E_m\, V_m = (40\text{x}10^6)(0.5) + (0.56\text{x}10^6)(0.50)$

$\underline{E_c = 20.3\text{x}10^6 \text{ psi}}$

Specific weight: $\gamma_c = \gamma_f\, V_f + \gamma_m\, V_m = (0.065)(0.50) + (0.047)(0.50)$

$\underline{\gamma_c = 0.056 \text{ lb/in}^3}$

2-64 Given: $V_f = 0.50$; Fibers are high modulus carbon; Matrix is Epoxy

See Table 2-15 for data. $V_m = 1 - V_f = 1.0 - 0.50 = 0.50$

Use Equation (2-10): $s_{uc} = s_{uf}\, V_f + \sigma_m'\, V_m$

Strain at which fibers would fail: $\varepsilon_f = s_{uf} / E_f = (325\text{x}\ 10^3 \text{ psi})/(100\text{x}10^6 \text{ psi})$

$\varepsilon_f = 0.00325$

Stress in matrix at this strain: $\sigma_m' = E_m\, \varepsilon = (0.56\text{x}10^6 \text{ psi})(0.00325) = 1820 \text{ psi}$

Then: $s_{uc} = (325\text{x}\ 10^3 \text{ psi})(0.50) + (1820 \text{ psi})(0.50) = \underline{163\text{x}10^3 \text{ psi}}$

Modulus of elasticity: $E_c = E_f\, V_f + E_m\, V_m = (100\text{x}10^6)(0.5) + (0.56\text{x}10^6)(0.50)$

$\underline{E_c = 50.3\text{x}10^6 \text{ psi}}$

Specific weight: $\gamma_c = \gamma_f\, V_f + \gamma_m\, V_m = (0.078)(0.50) + (0.047)(0.50)$

$\underline{\gamma_c = 0.0625 \text{ lb/in}^3}$

2-65 Given: $V_f = 0.50$; Fibers are aramid; Matrix is Epoxy

See Table 2-15 for data. $V_m = 1 - V_f = 1.0 - 0.50 = 0.50$

Use Equation (2-10): $s_{uc} = s_{uf}\, V_f + \sigma_m'\, V_m$

Strain at which fibers would fail: $\varepsilon_f = s_{uf} / E_f = (500\text{x}\ 10^3 \text{ psi})/(19\text{x}10^6 \text{ psi})$

$\varepsilon_f = 0.0263$

Stress in matrix at this strain: $\sigma_m' = E_m\, \varepsilon = (0.56\text{x}10^6 \text{ psi})(0.0263) = 14\ 740 \text{ psi}$

Then: $s_{uc} = (500\text{x}\ 10^3 \text{ psi})(0.50) + (14\ 740 \text{ psi})(0.50) = \underline{257\text{x}10^3 \text{ psi}}$

Modulus of elasticity: $E_c = E_f\, V_f + E_m\, V_m = (19\text{x}10^6)(0.5) + (0.56\text{x}10^6)(0.50)$

$\underline{E_c = 9.78\text{x}10^6 \text{ psi}}$

Specific weight: $\gamma_c = \gamma_f\, V_f + \gamma_m\, V_m = (0.052)(0.50) + (0.047)(0.50)$

$\underline{\gamma_c = 0.0495 \text{ lb/in}^3}$

Solutions to Problems 2-66 to 2-67: Some data approximated from Figure P2-66.
Most accurate values are for Ultimate strength (b.)and % elongation (f).
Elastic limit (d.) estimated between proportional limit (c.) and yield strength (a.)
Modulus of elasticity (e.) computed from (Δ stress / Δ strain). Data are approximated
Materials found from Appendixes A-13 through A-17 matching s_u, s_y, % Elongation, and E

2-66
a. $s_y = 73$ ksi - Offset
b. $s_u = 83$ ksi
c. $s_p = 60$ ksi
d. $s_{el} = 67$ ksi
e. $E = 10.0\text{x}10^6$ psi
f. 11% Elongation
g. Ductile
h. Aluminum
I. 7075-T6

2-67
a. $s_y = 173$ ksi Yield point
b. $s_u = 187$ ksi
c. $s_p = 162$ ksi
d. $s_{el} = 168$ ksi
e. $E = 29.0\text{x}10^6$ psi
f. 15% Elongation
g. Ductile
h. Steel
I. AISI 4140 OQT 900

2-68
a. $s_y = 62$ ksi Offset
b. $s_u = 75$ ksi
c. $s_p = 50$ ksi
d. $s_{el} = 56$ ksi
e. $E = 16.7\text{x}10^6$ psi
f. 15% Elongation
g. Ductile
h. Copper Alloy
I. C54400 Bronze-hard

2-69
a. $s_y = 49$ ksi - Yield point
b. $s_u = 65$ ksi
c. $s_p = 46$ ksi
d. $s_{el} = 48$ ksi
e. $E = 26.5\text{x}10^6$ psi
f. 36% Elongation
g. Ductile
h. Steel
I. AISI 1020 CD

2-70
a. No s_y - Brittle
b. $s_u = 55$ ksi
c. $s_p = 50$ ksi
d. $s_{el} = 53$ ksi
e. $E = 20.0\text{x}10^6$ psi
f. 0.5% Elongation
g. Brittle
h. Cast Iron
I. ASTM A48 Grade 60

2-71
a. $s_y = 53$ ksi - Offset
b. $s_u = 59$ ksi
c. $s_p = 31$ ksi
d. $s_{el} = 42$ ksi
e. $E = 12.0\text{x}10^6$ psi
f. 5.0% Elongation
g. Borderline Brittle/Ductile
h. Zinc
I. Cast ZA-12

2-72
a. $s_y = 35$ ksi - Yield point
b. $s_u = 57$ ksi
c. $s_p = 30$ ksi
d. $s_{el} = 27$ ksi
e. $E = 26\text{x}10^6$ psi
f. 21% Elongation
g. Ductile
h. Structural Steel
I. ASTM A36

2-73
a. $s_y = 19$ ksi - Offset
b. $s_u = 40$ ksi
c. $s_p = 14$ ksi
d. $s_{el} = 17$ ksi
e. $E = 6\text{x}10^6$ psi
f. 5% Elongation
g. Borderline Brittle/Ductile
h. Magnesium
I. ASTM AZ 63A-T6

2-74 a. $s_y = 155$ ksi - Offset
b. $s_u = 170$ ksi
c. $s_p = 142$ ksi
d. $s_{el} = 149$ ksi
e. $E = 16.5\text{x}10^6$ psi
f. 8% Elongation
g. Ductile
h. Titanium
I. 6Al-4V

2-75 a. $s_y = 40$ ksi - Offset
b. $s_u = 45$ ksi
c. $s_p = 30$ ksi
d. $s_{el} = 35$ ksi
e. $E = 10.0\text{x}10^6$ psi
f. 17% Elongation
g. Ductile
h. Aluminum
I. 6061-T6

2-76 a. $s_y = 80$ ksi - Offset
b. $s_u = 90$ ksi
c. $s_p = 62$ ksi
d. $s_{el} = 71$ ksi
e. $E = 26\text{x}10^6$ psi
f. 15% Elongation
g. Ductile
h. Stainless Steel
I. AISI 430 full hard

2-77 a. $s_y = 80$ ksi - Offset
b. $s_u = 95$ ksi
c. $s_p = 55$ ksi
d. $s_{el} = 68$ ksi
e. $E = 26\text{x}10^6$ psi
f. 2.0% Elongation
g. Brittle, but does yield
h. Malleable Iron
I. ASTM A220 Grade 80002